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LEAD SHIELD TO IMPROVE DETECTION OF HIGH-ENERGY PHOTONS OF ^{38}K AND ^{42}K BY SCINTILLATION CAMERAS

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Research was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences - National Research Council.

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ABSTRACT

A lead shield was designed and tested for use with the pinhole collimator of the Nuclear-Chicago HP scintillation camera to detect photons of ^{38}K and ^{42}K for cardiac scanning. A discussion of each isotope with reference to cardiac scanning is given with especial emphasis upon the problems of imaging high-energy photons, i.e., 511 keV or higher with the presently available scintillation cameras.

I. INTRODUCTION

With the recent surge of interest in myocardial imaging using annihilation photons of 511-keV energies, a method to detect these photons using the presently available scintillation cameras is needed. Positron cameras are available for detection, but these are difficult to obtain, and costly.[2] Therefore, it seemed reasonable to develop a simple lead shield for use with the readily available pinhole collimator adapted for the Nuclear-Chicago HP scintillation camera. This report describes specific aspects of the design and construction of such a lead shield to improve imaging of high-energy photons, and describes the use of ^{38}K and ^{42}K for myocardial scanning.

II. MATERIALS AND METHODS

Following several routine examinations of the pinhole collimator, using potassium-38 as a high-energy photon emitter, it was found that the design of the present pinhole collimator had several disadvantages. First and foremost, by holding the radiation source in the field of view of the pinhole collimator and moving it laterally around the sides of the collimator, it was noted that large amounts of the emitted photons penetrated the walls of the pinhole collimator and interacted with the 1.3-cm thick NaI(Tl) crystal of the camera, i.e., reflected by little change in count rate. It was also evident that through the junction of the camera head and the collimator (Figure 1) a large amount of radiation penetrated, adding to the "edge packing" effect on the crystal.

Anger and Davis have previously shown that the probability of photopeak interaction with the 1.3-cm thick NaI(Tl) crystal of the Anger camera by .511 MeV photons is approximately 17 percent.[1] Since a small number of the emitted photons interact

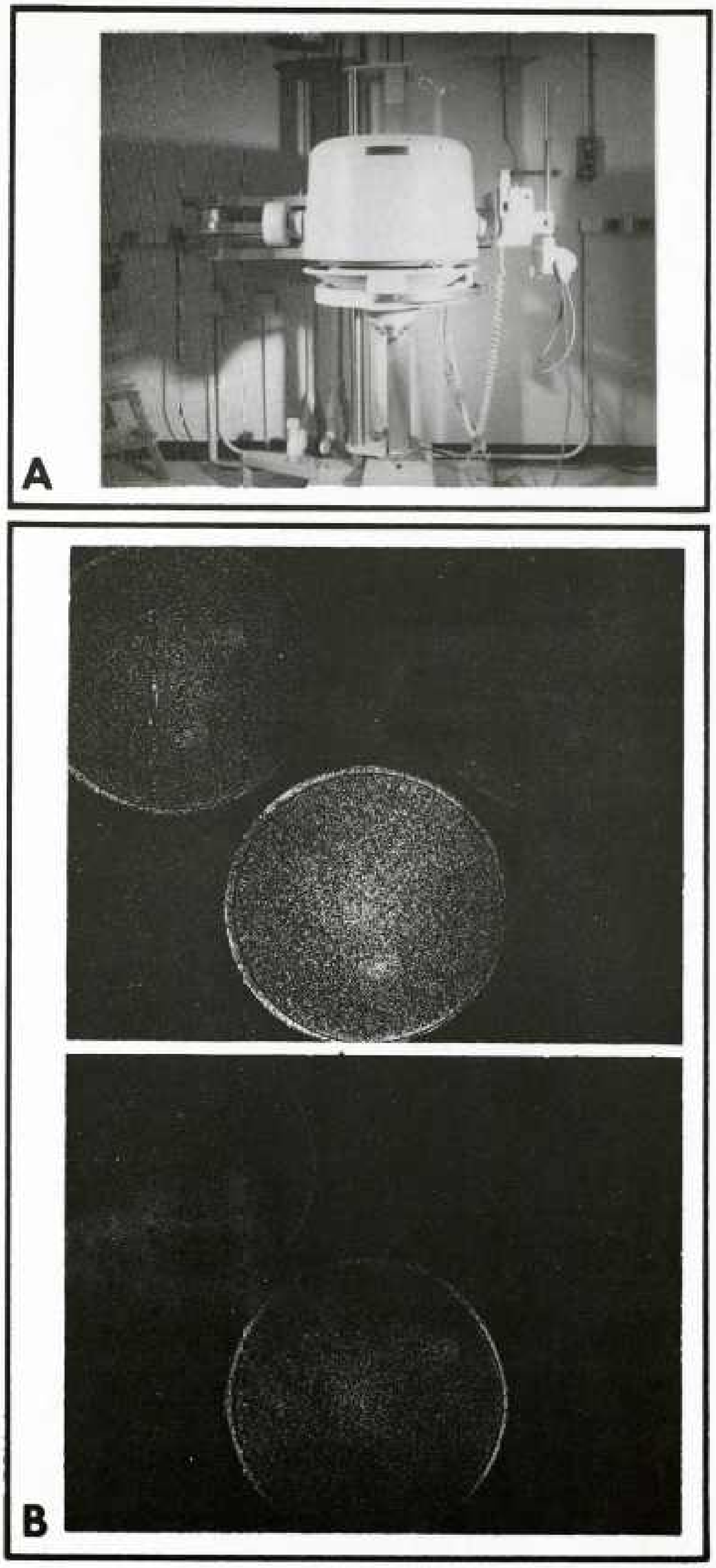


Figure 1.
Photograph of the pinhole collimator and camera head assembly showing the area where the two are joined (A) and the amount of penetration with high (511 keV) photons that occurs at that junction (B)

with the crystal, and since a large amount of the emitted photons penetrate the pinhole collimator, a lead shield was designed to cover the collimator to improve in detection characteristics. In designing this lead shield, it was necessary to consider all the photons that come from potassium-38 decay. Potassium-38 decays by emitting 2.68-MeV (maximum) photons which annihilate in vivo to produce .511 MeV photons. It has a half-life (T-1/2) of 7.7 min. Two hundred percent of the 511 keV annihilation $\pm$ gamma rays are available for imaging.[1,5] A lead protective shield, covering the detecting crystal, needed to be designed such that it would be thick enough to absorb not only the penetrating 511 keV energies, but also the 2.17-MeV gamma emissions. In addition, since it was found that a significant amount of "photon leak" occurred at the junction of the pinhole collimator with the scintillation camera head, the lead shield also had to be designed to cover that portion of the instrument. A large amount of lead, calculated to be approximately 4 cm thick, was needed, since the calculated half-thicknesses for these high-energy radiations from potassium-38 are approximately 4.3 cm for NaI, 7.2 cm for water, and .42 cm for lead.[1] Since the weight of the shield itself would be extremely heavy, construction of a durable movable cart to hold the collimator was necessary.

III. RESULTS AND DISCUSSION

Figure 2 shows the complete design of the shielding apparatus, including its carrying cart. A study of the myocardium of a beagle, following the injection of 5 millicuries of potassium-38, with (A) and without (B) the collimator is shown in Figure 3. The collimator does an adequate job of absorbing the unwanted radiation, and therefore, the myocardial area can be satisfactorily visualized.

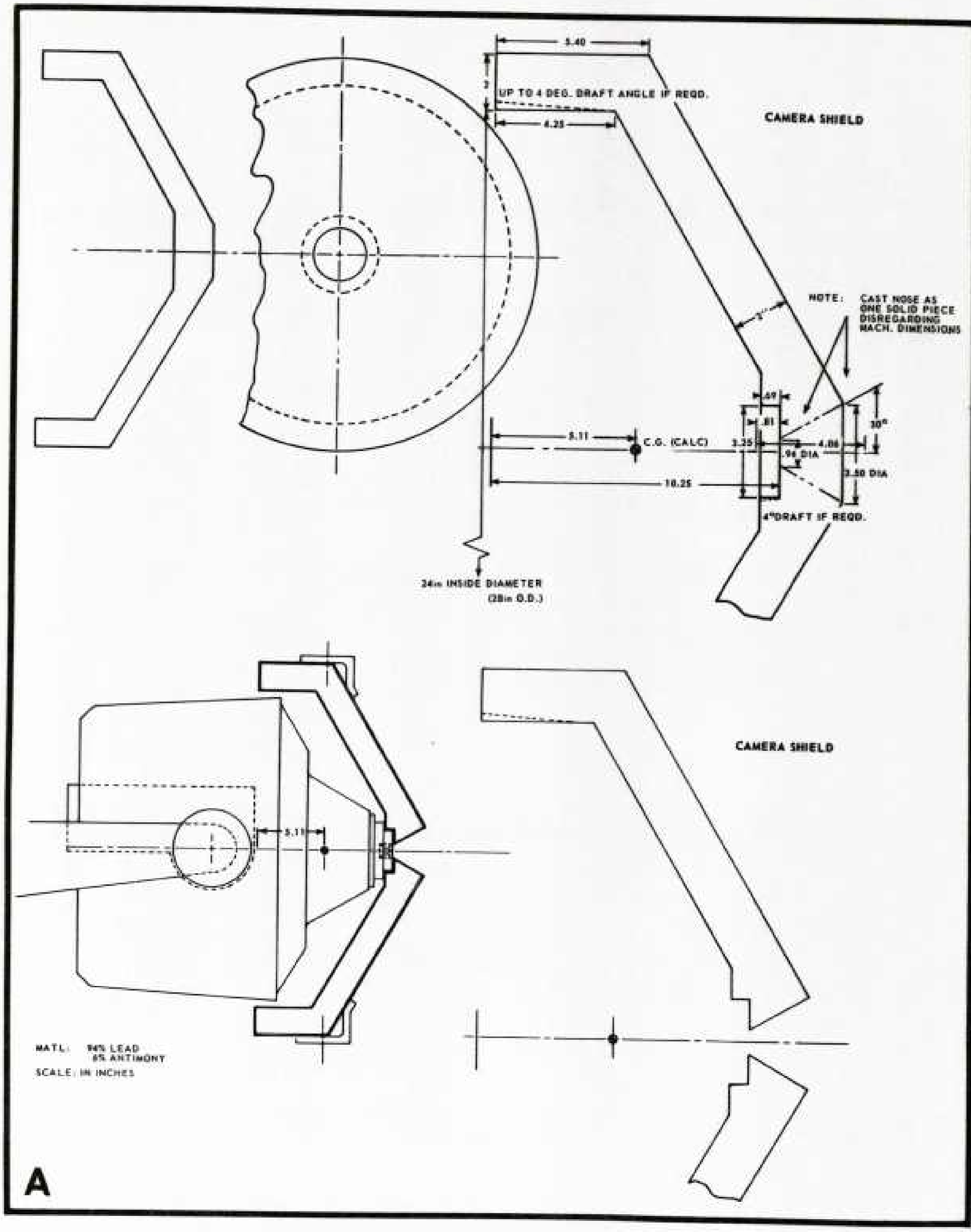


Figure 2. Diagram drawings of the camera lead shield assembly (A and B) with comparison photographs of the shield and pinhole collimator together (C through H)

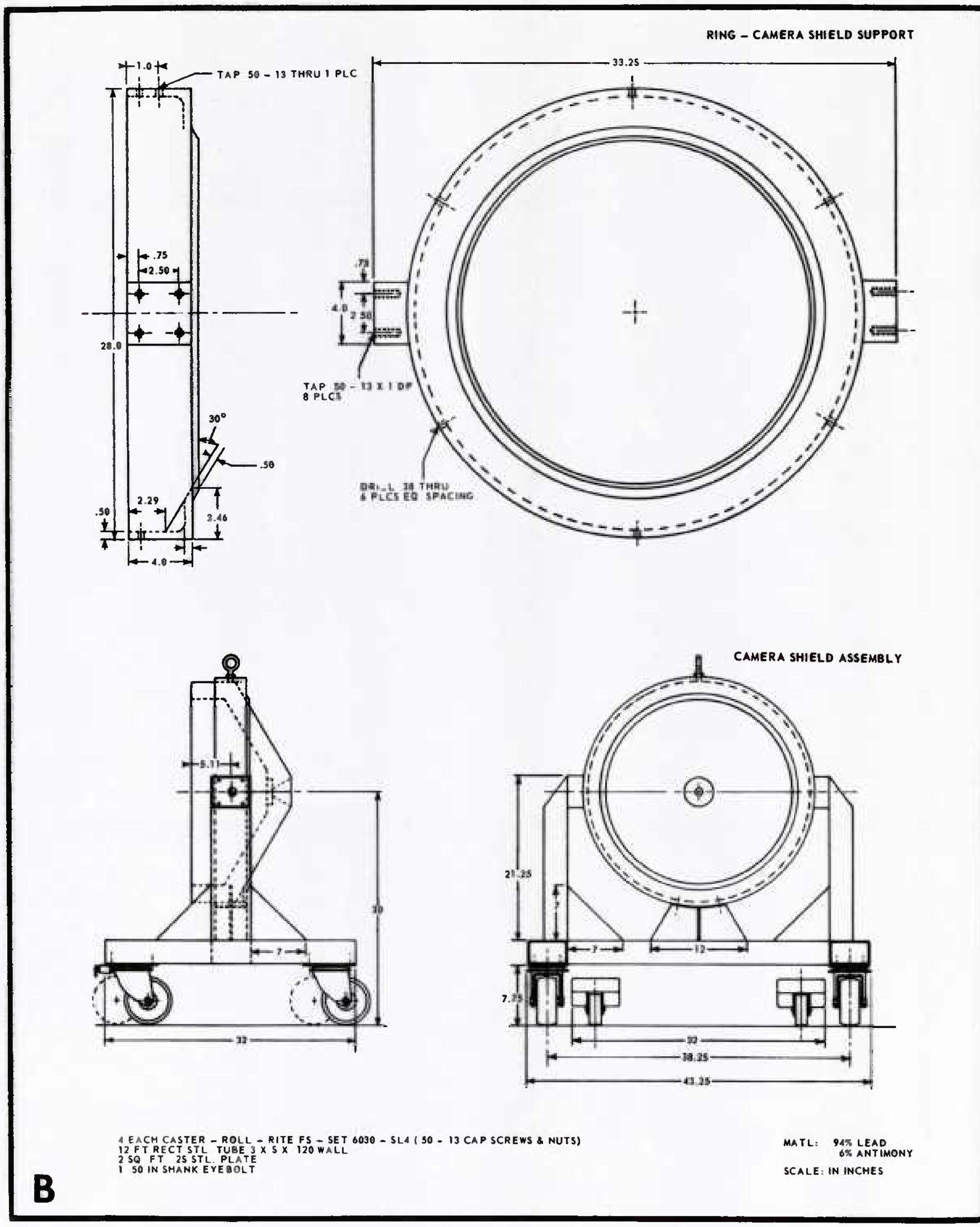
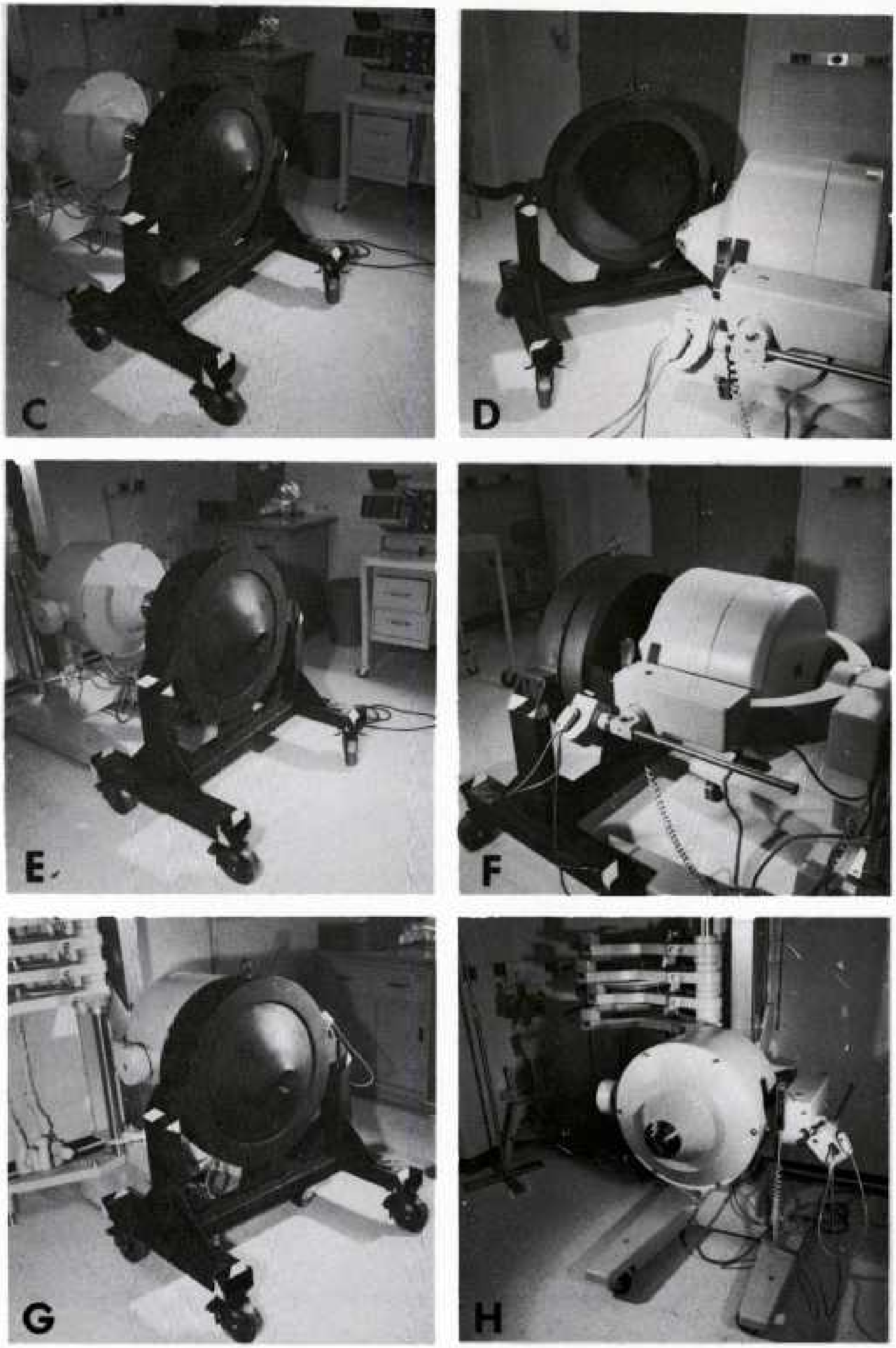


Figure 2 (continued)



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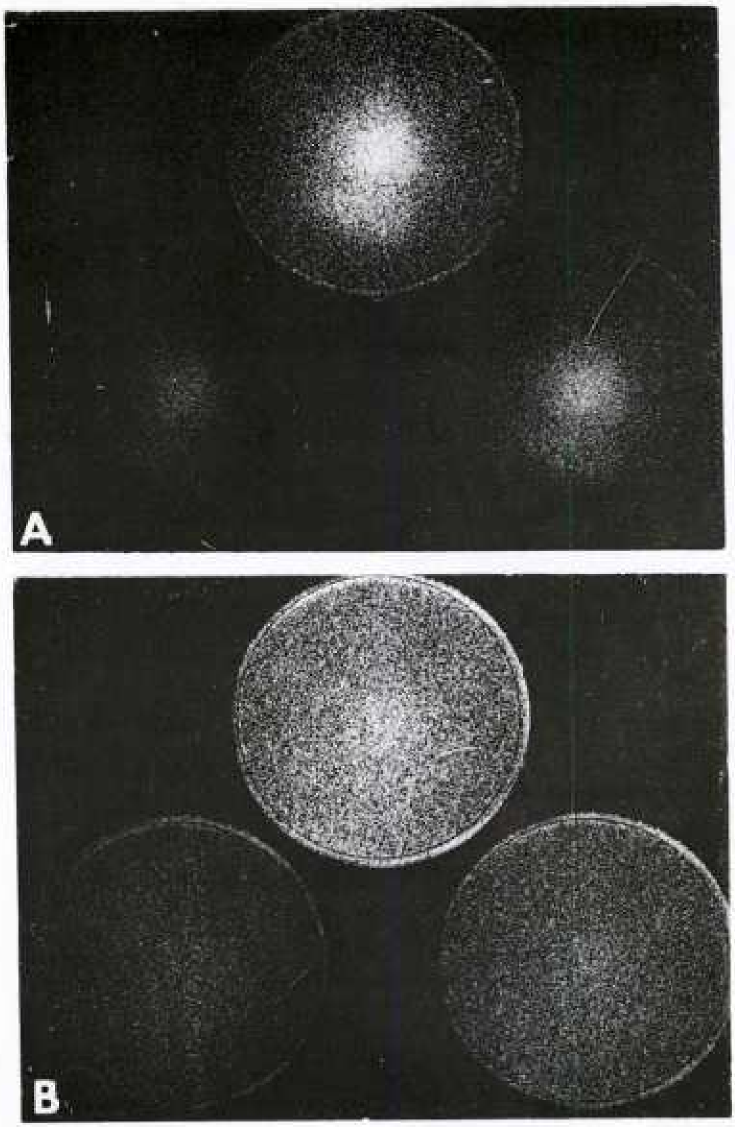

Figure 3.
^{38}K cardiac study in an animal depicting the good image that can be obtained (A) when the shield is used, and how poor the image is when the lead shield is removed (B)

Potassium-38 and potassium-43 are good isotopes for imaging the heart, due to their roughly short T-1/2, 7.7 min for ^{38}K, 22.4 h for ^{43}K, and the fact that their dominant gamma emissions appear to be in the detectable energy range for the scintillation camera.[1,4] Potassium-43 emits .373-MeV gamma disintegrations, a .39-MeV gamma (18 percent), a .59-MeV gamma (13 percent), a .619-MeV gamma (81 percent), and a 1.1-MeV gamma (2 percent). It has been shown that calculated "narrow beam"

half-thickness of these, in lead, exceeds 0.5 cm.[3] Therefore, image resolution can be degraded due to collimator septal or edge penetrations. Moreover, the calculated probability of photopeak interaction with the NaI(Tl) of the scintillation camera is only 13 percent for 0.619 MeV gamma rays (emitted 81 percent of the time by potassium-43).[1]

Poe has compared precordial uptake and clearance of potassium-42 and found that it reaches a plateau of concentration in the myocardium within a period of 5-20 minutes after bolus injection into the jugular vein.[6] He also found that approximately 22 percent remains in the blood after 2 minutes following injection, and scanning, therefore, can commence immediately. After bolus injection of ^{42}K into the anterior descending coronary artery, 71 percent is extracted during the first circulation through the coronary capillary bed. This indicates that the amount of potassium-42 available for recirculation is small. In addition, ^{42}K clears quickly from the heart with a 78-minute biological T-1/2,[6] allowing for immediate rapid and sequential imaging.

Potassium-38, however, seems to be better than potassium-43 for imaging the heart, for its physical half-life of 7.7 minutes closely matches the maximum uptake time of the isotope in the myocardium (in contrast to the 175-fold longer 22.4-hour physical T-1/2 of ^{43}K).[5]

The advantages of potassium-38 and potassium-43 for rapid myocardial imaging stem mainly from their superior resolution, as well as from improved statistics obtainable due to the low radiation absorbed doses.[5]

Use of the scintillation camera in positron mode (580 on the isotope setting with 20 to 30 percent window) can adequately detect the radiation emitted from the potassium-38 isotope with the lead shield in place. In addition, when computer processed data are added to the study, one can obtain additional quantitative information. Tomographic capabilities can also improve imaging of potassium-38[5] by discriminating against the accumulation of the isotope in the surrounding tissues particularly the muscles of the thorax.

The new MGH positron camera may give improved imaging for the 511 keV isotopes but, again, it is highly expensive as compared to the single lead shield described herein. The 11-minute average life of potassium-38 has another positive characteristic in that it allows repetitive and multiple views of the myocardium as residual activity from a previous dose disappears rapidly, or can be subtracted out by the use of computers. It also goes to the myocardium by normal physiological pathways which is ideal when studying myocardial function.[7]

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